1. B

[1]

2. A

[1]

3. A

[1]

4. (a) (i) the (minimum) energy required to completely separate the nucleons of a nucleus / the energy released when a nucleus is assembled; 1

(ii) mass defect is $94 \times 1.007276 + 145 \times 1.008665 - 238.990396 = 1.95\text{u}$;
binding energy is $1.95 \times 931.5 = 1816$ MeV;
binding energy per nucleon is $\frac{1816}{239}$ MeV;
= 7.6 MeV 3

(b) (i) $x = 3$; 1

(ii) binding energy of plutonium is $7.6 \times 239 = 1816 \approx 1800$MeV
(known in (ii))
binding energy of products is $8.6 \times 91 + 8.2 \times 146 = 1980 \approx 2000$ MeV;
energy released is $(2000 - 1800) = 200$MeV; 2

(c) the electric force is repulsive/tends to split the nucleus;
the electric force acts on protons, the strong nuclear force acts on nucleons;
the nuclear force is attractive/binds the nucleons;
but the electric force is long range whereas the nuclear force is short range;
so adding more neutrons (compared to protons) contributes to binding and does not add to tendency to split the nucleus / a proton repels every other proton (in the nucleus) so extra neutrons are needed for binding; 4 max

[11]

5. light consists of photons/quanta/packets of energy;
each photon has energy $E = hf$ / photon energy depends on frequency;
a certain amount of energy is required to eject an electron from the metal;
if photon energy is less than this energy, no electrons are emitted; 4

[4]

6. (a) $E = \frac{hc}{\lambda}$;

$= \frac{6.63\times10^{-34}\times3.00\times10^{8}}{658\times10^{-9}} = 3.02\times10^{-19}$;

$= \frac{3.02\times10^{-19}}{1.60\times10^{-19}}$;

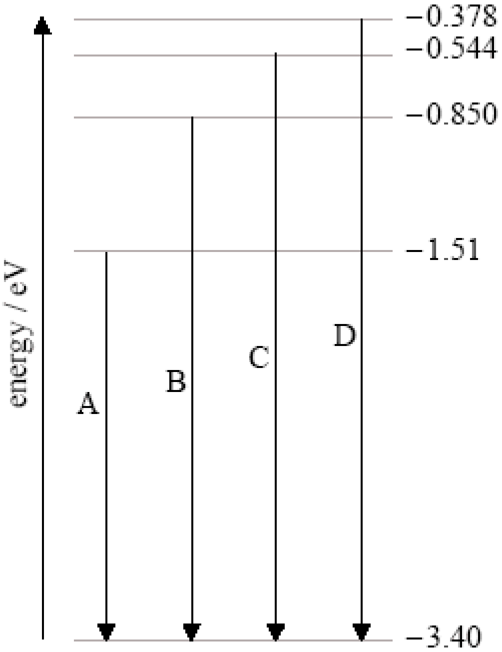
$= 1.89\text{eV}$

or

the photon of wavelength 658nm is the longest (in the emission graph);
therefore it has the shortest frequency and lowest energy (from $E = hf$);
therefore it arises from the transition between the –1.51eV and the –3.40 eV energy levels which have a difference of 1.89eV; 3

(b) (i) see diagram below; 1

(ii) see diagram below;
All three must be correct for the mark. 1



(c) at higher energy levels, energy levels become closer together;
the energy differences between higher energy levels and the lower level ($n = 2$) become more equal;
hence the difference in wavelength of emitted photons decreases / *OWTTE*; 3

[8]

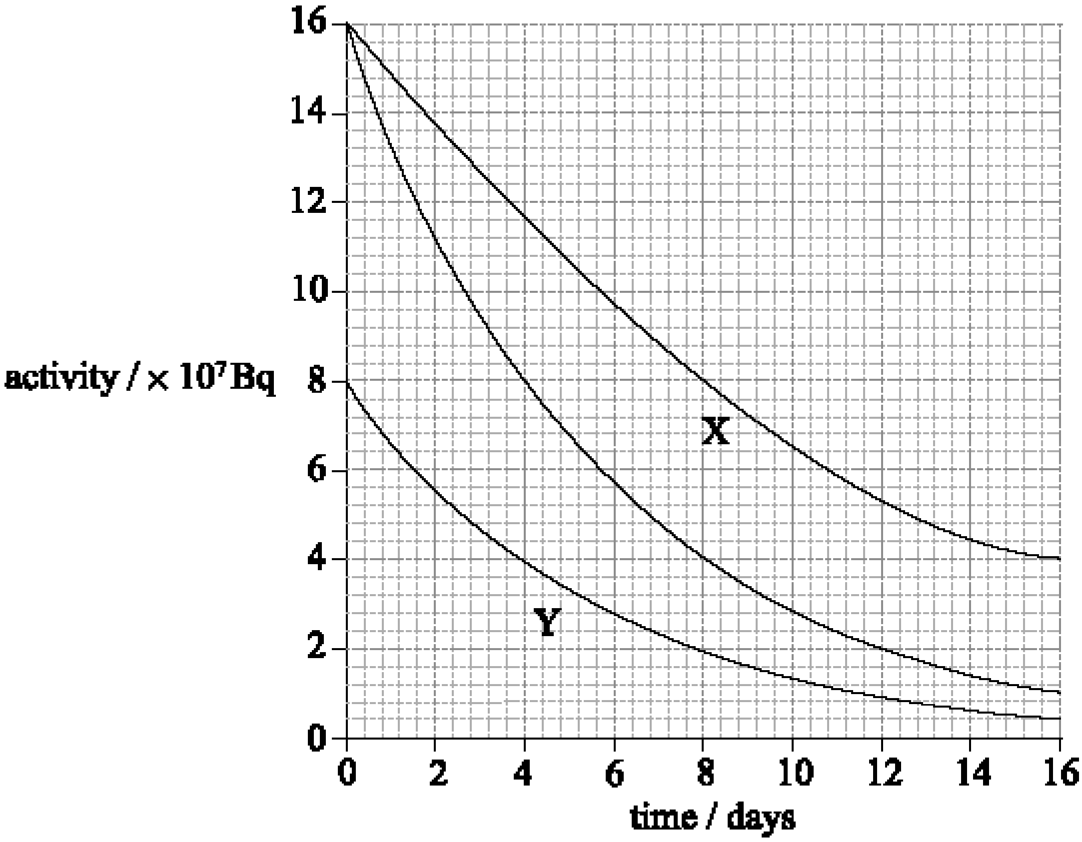
7. (a) ${}^{124}_{53}\text{I} \rightarrow {}^{124}_{52}\text{Te} + {}^{0}_{1}\beta^{+}$;
${}^{0}_{0}\nu$ / ν;
Do not allow an antineutrino.
*Award **[1 max]** for* ${}^{124}_{53}\text{I} \rightarrow {}^{124}_{54}\text{Te} + {}^{0}_{-1}\beta^{-} + \bar{\nu}$.

(b) (i) 4 days; 1

(ii) $\lambda = \frac{\ln 2}{T_{\frac{1}{2}}} = \frac{\ln 2}{4}$ = (0.173 day^{-1});
$A = A_0 e^{-\lambda t} = 16 \times 10^7 \times e^{-0.173 \times 21}$ (Bq);
$A = 4.2 \times 10^6$ Bq;
*Award **[2 max]** for bald answer in range* 4.2–4.5 × 10^6 Bq,
or linear interpolation between half lives giving 4.4 × 10^6 Bq.

(iii) graph passing through or near (0,16), (8,8) and (16,4) – see below; 1

(iv) graph passing through or near (0,8), (4,4) and (8,2) – see below;
Do not penalize if graph does not pass through (12,1) and (16,0.5). 2



[8]

8. A **[1]**

9. C **[1]**

10. C **[1]**

11. B **[1]**

12. B

[1]

13. B

[1]

14. (a) a function whose (absolute squared) value may be used to calculate the probability of finding a particle near a given position / quantity related to the probability of finding an electron near a given position/at a given position; 1

(b) middle of the box / (near) 0.5×10^{-10} m; 1

(c) the de Broglie wavelength is 2.0×10^{-10} m;

$p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{2.2 \times 10^{-10}} = 3.3 \times 10^{-24}$ Ns; 2

(d) difference in energy is

$\Delta E \left(= -\frac{2.18 \times 10^{-18}}{2^2} + \frac{2.18 \times 10^{-18}}{1^2} \right) = 1.635 \times 10^{-18}$ J;

$\lambda = \frac{hc}{\Delta E}$;

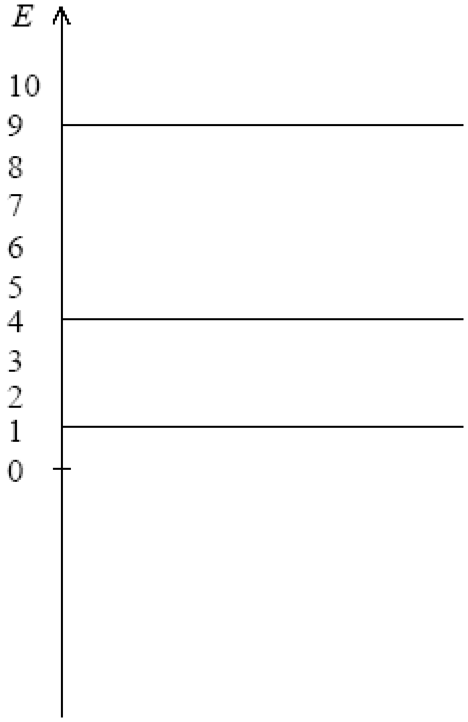
$\lambda = \left(\frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{1.635 \times 10^{-18}} \right) = 1.22 \times 10^{-7}$ m; 3

(e) (i) attempt at using the energy – time uncertainty relation;

$\Delta E \left(= \frac{h}{4\pi \Delta t} = \frac{6.63 \times 10^{-34}}{4\pi \times 1.0 \times 10^{-10}} \right) = 5.3 \times 10^{-25}$ J; 2

(ii) the wavelength of the photons is determined by the difference in energy between the two levels;
and that energy difference is not well defined/definite/not always the same (because of the uncertainty principle); 2

(f) energy levels all with strictly positive energy;
difference between levels increasing with increasing *n*; 2



Judge separation of levels by eye – there will not be numbers on the candidates' graphs.

[13]

15. A

[1]

16. C

[1]

17. B

[1]

18. (a) $\frac{1}{2}$th mass of an <u>atom</u> of carbon–12/^{12}C; 1

(b) (254.1001 × 931.5 =) 236.7(GeV c^{-2}); (*only accept answer in GeV* c^{-2}) 1

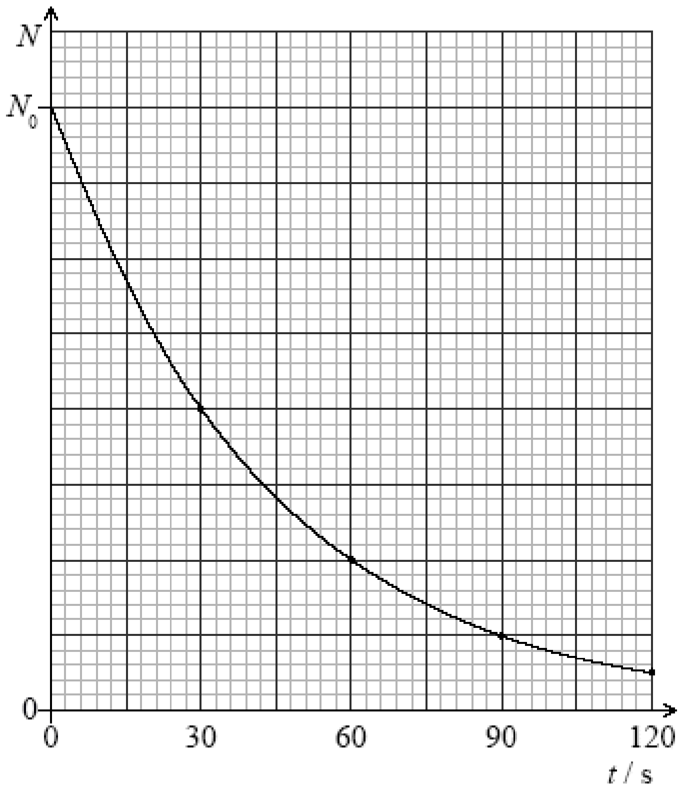
(c) (i) proton / hydrogen nucleus / H^+ / ${}^1_1H$/${}^1_1p$; 1

(ii) Δm = (16.8383 – [3.7428 + 13.0942] =) 0.0013(GeV c^{-2});
energy required for reaction = 1.3 (MeV);
KE of ${}^{17}_{8}O$ + **X** = (7.68 – 1.3 =) 6.4 (6.38) MeV; (*allow correct answer in any valid energy unit)* 3

(d) (i) (nuclei of same element with) same proton number, different number of neutrons / *OWTTE*; 1

(ii) the time for the activity of a sample to reduce by half / time for the number of the radioactive nuclei to halve from original value; 1

(e) scale drawn on t axis; *(allow 10 grid squares = 30 s or 40 s)*
smooth curve passes through $\frac{N_0}{2}$ at 30 s, $\frac{N_0}{4}$ at 60 s, $\frac{N_0}{8}$ at 90 s, $\frac{N_0}{16}$ at 120 s (to within 1 square); (*points not necessary)* 2



[10]

19. (a) ejection of electron from metal surface following absorption of em radiation/photon; 1

(b) (i) energy of one photon = $6.67 \times 10^{-34} \times 8.7 \times 10^{14}$(= 5.8×10^{19} J);

number of electrons released from surface per second = $\frac{9.0\times10^{-6}\times1.1\times10^{-3}}{5.8\times10^{-19}}$

= 1.7×10^{10};

current = $1.7 \times 10^{10} \times 1.6 \times 10^{-19}$;

= 2.7 nA 3

(ii) 2.4 eV ***or*** 3.9×10^{-19} J; 1

[5]

20. (a) particles have an associated wavelength;

wavelength = $\frac{h}{mv}$ ***or*** $\frac{h}{p}$; (*symbols must be defined)* 2

(b) $\lambda = \frac{h}{\sqrt{2\text{meV}}}$

8.3×10^{-13} m; 2

(c) (Heisenberg suggests that) $\Delta p \Delta x$ is a constant ***or*** $\geq \frac{h}{4\pi}$;

if λ is known then Δp is zero therefore uncertainty in position Δx is infinite/very large; 2

Award ***[1 max]*** *if* Δp *and* Δx *not defined.*

or

(the Uncertainty Principle states that) it is impossible to know the position and momentum of a particle at the same time;

if λ is precise then momentum is precise so position is not known;

[6]

21. (a) (i) probability that a nucleus decays in unit time; 1

(ii) $150 = 800e^{-1.2\times10^{-3}t}$;

1400 s; 2

(b) (i) 580 s; 1

(ii) activity/count rate measured at regular time intervals/for at least three half-lives;
plot graph activity/count rate versus time;
detail of determination of half-life from graph; 3

(c) beta energy spectrum is continuous and associated gamma spectrum is discrete;
difference in energies accounted for by existence of another particle; 2

or

if another particle not present;
then momentum not conserved in beta decay;

[9]

22. D

[1]

23. B

[1]

24. A

[1]

25. C

[1]